Adaptive Nulling: a new tool for interferometric planet detection

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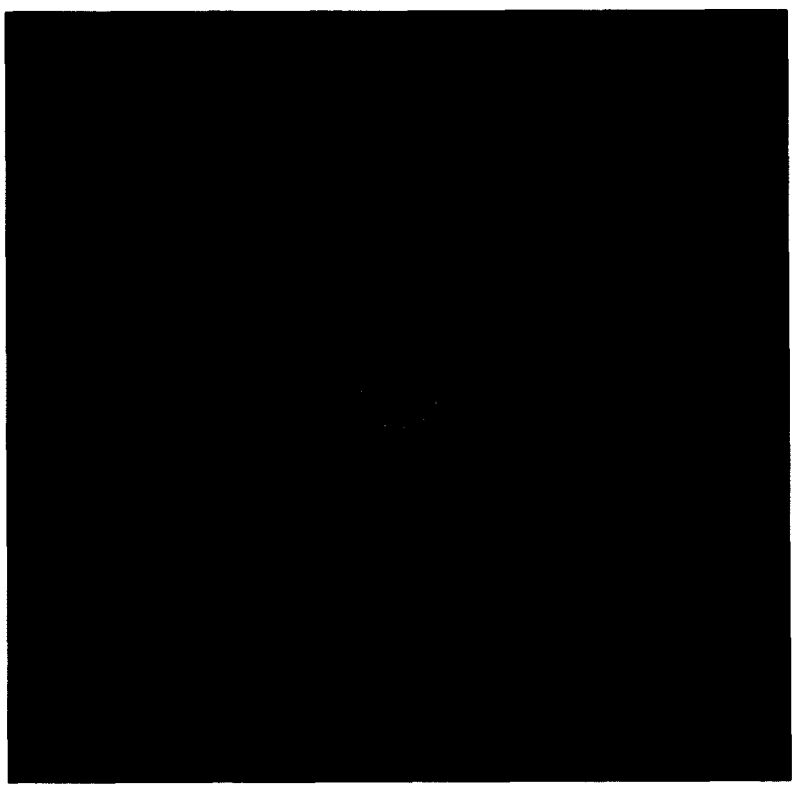
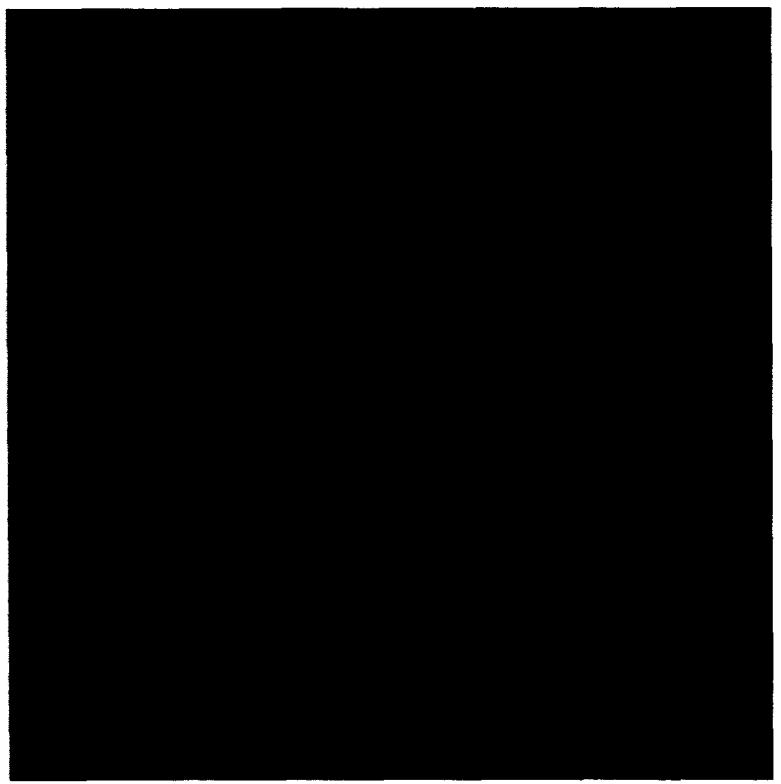
Outline

- Interferometric nulling
- The current approach
- Adaptive nulling
- Compensator design
- Benefits
- Challenges

- Explain why adaptive nulling is worth pursuing
- Demonstrate that it is feasible

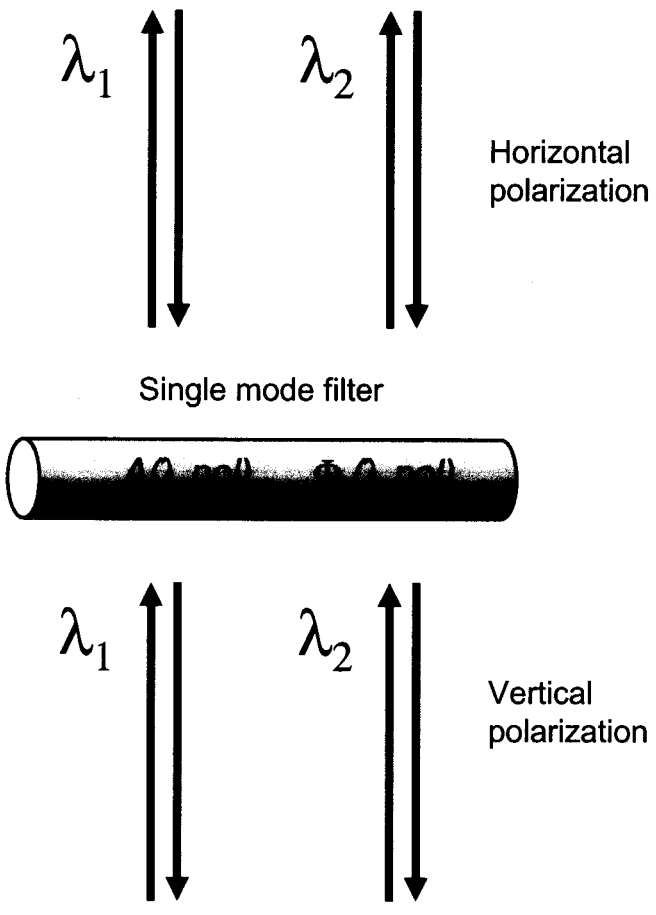
Interferometric nulling with TPF





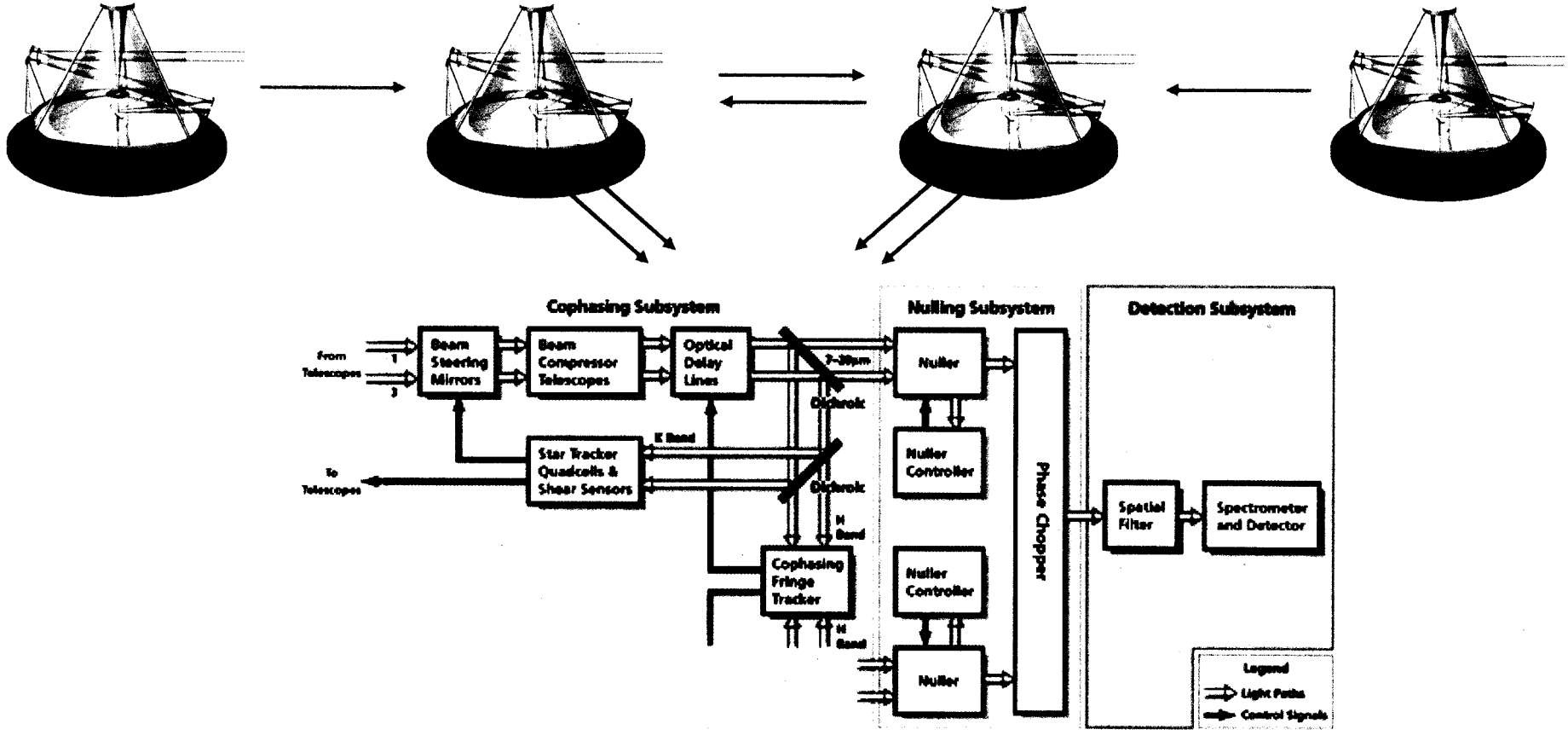
- Planet flux ~ 10^{-6} x star
- Null ~ 10^{-5} - 10^{-6}

Nulling



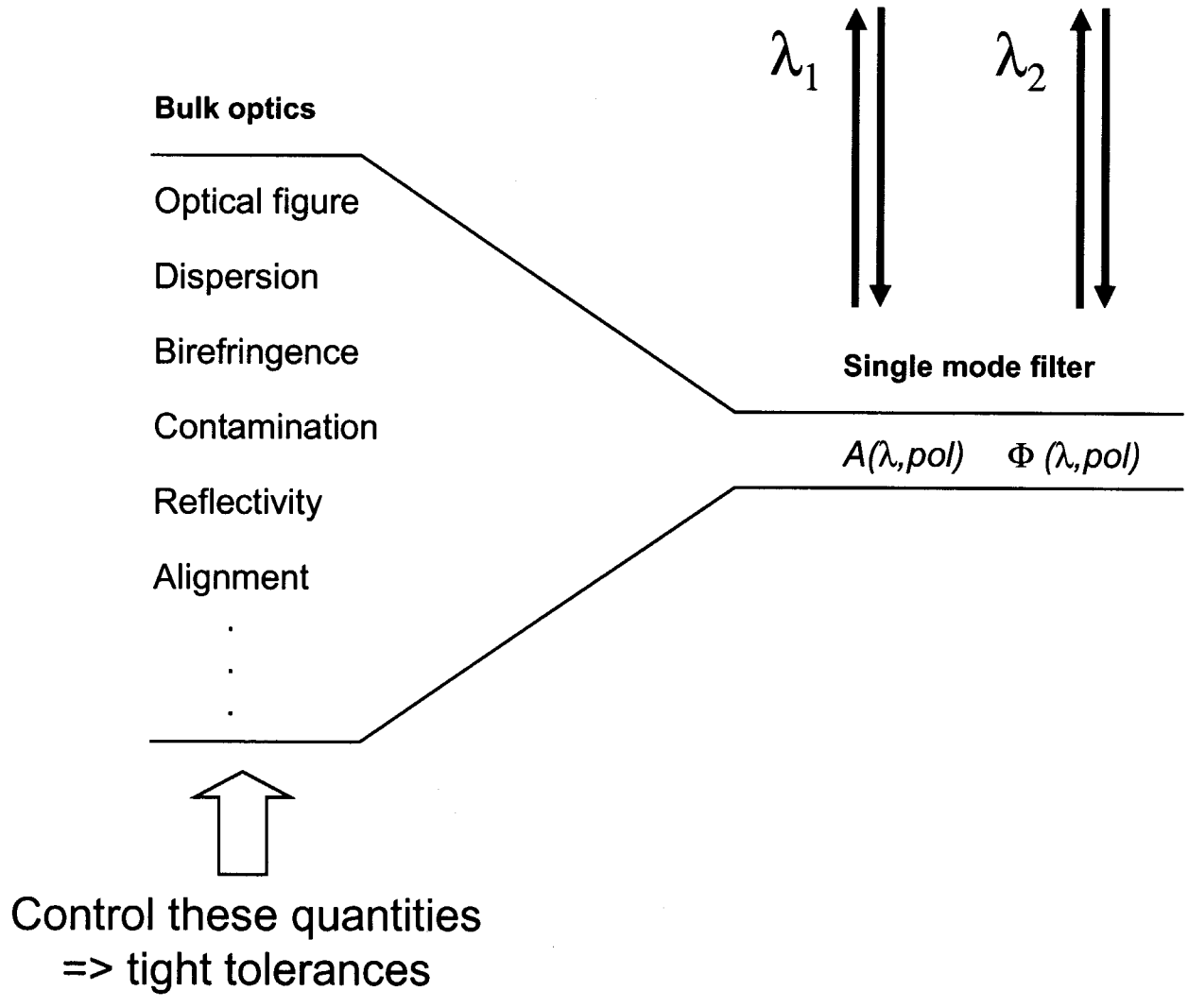
- For deep null require electric fields with
  - equal amplitudes
  - opposite phases
- simultaneously at each wavelength and polarization
- Single-mode filter makes it this simple (removes all spatial effects)

The TPF optical system

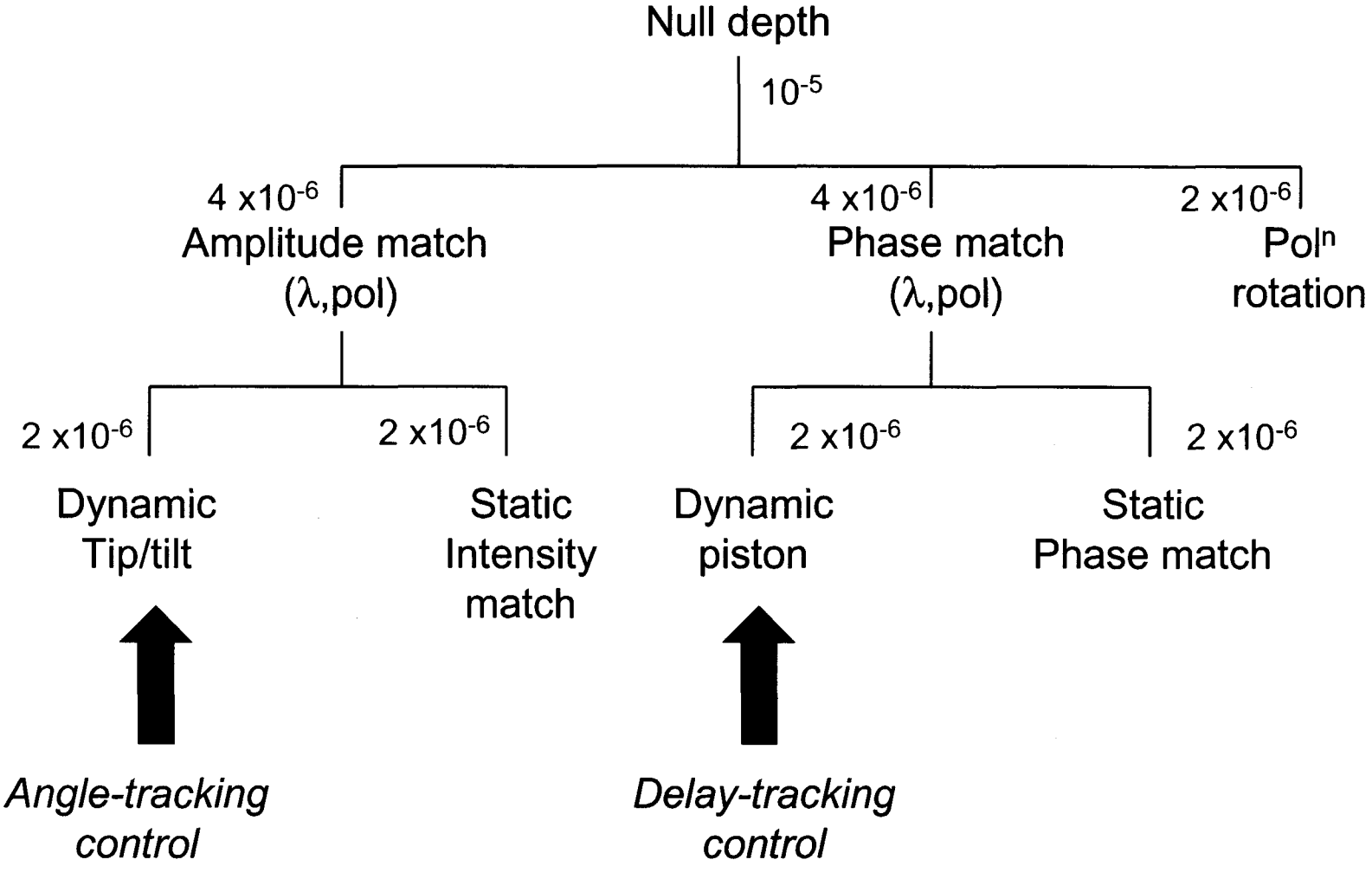


- The nuller is the *whole* instrument system, not just the nulling beam combiner
- A perturbation anywhere in the beam train will impact the null
- Focus has been on the nulling beam combiner

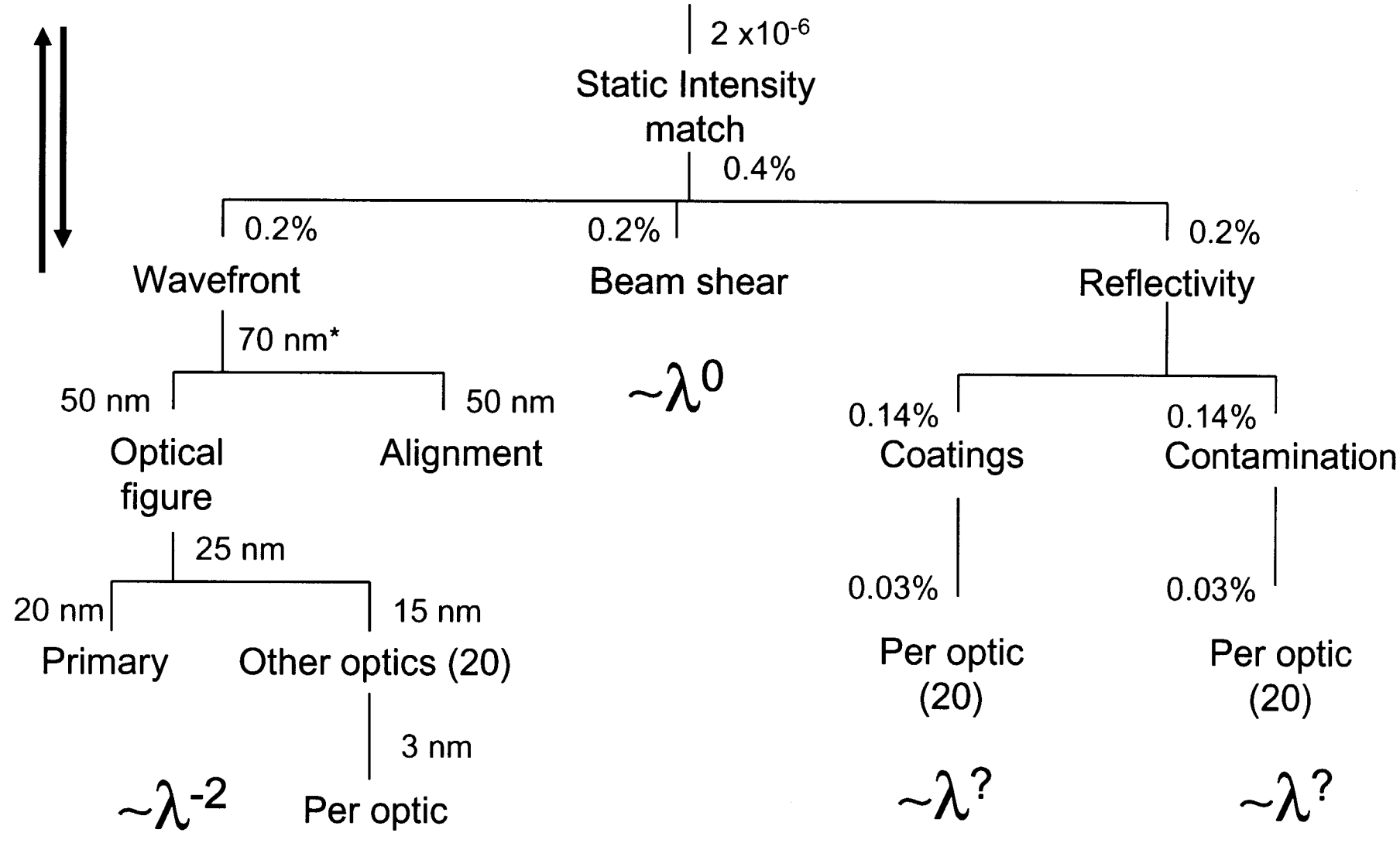
Current approach



Nulling Requirements

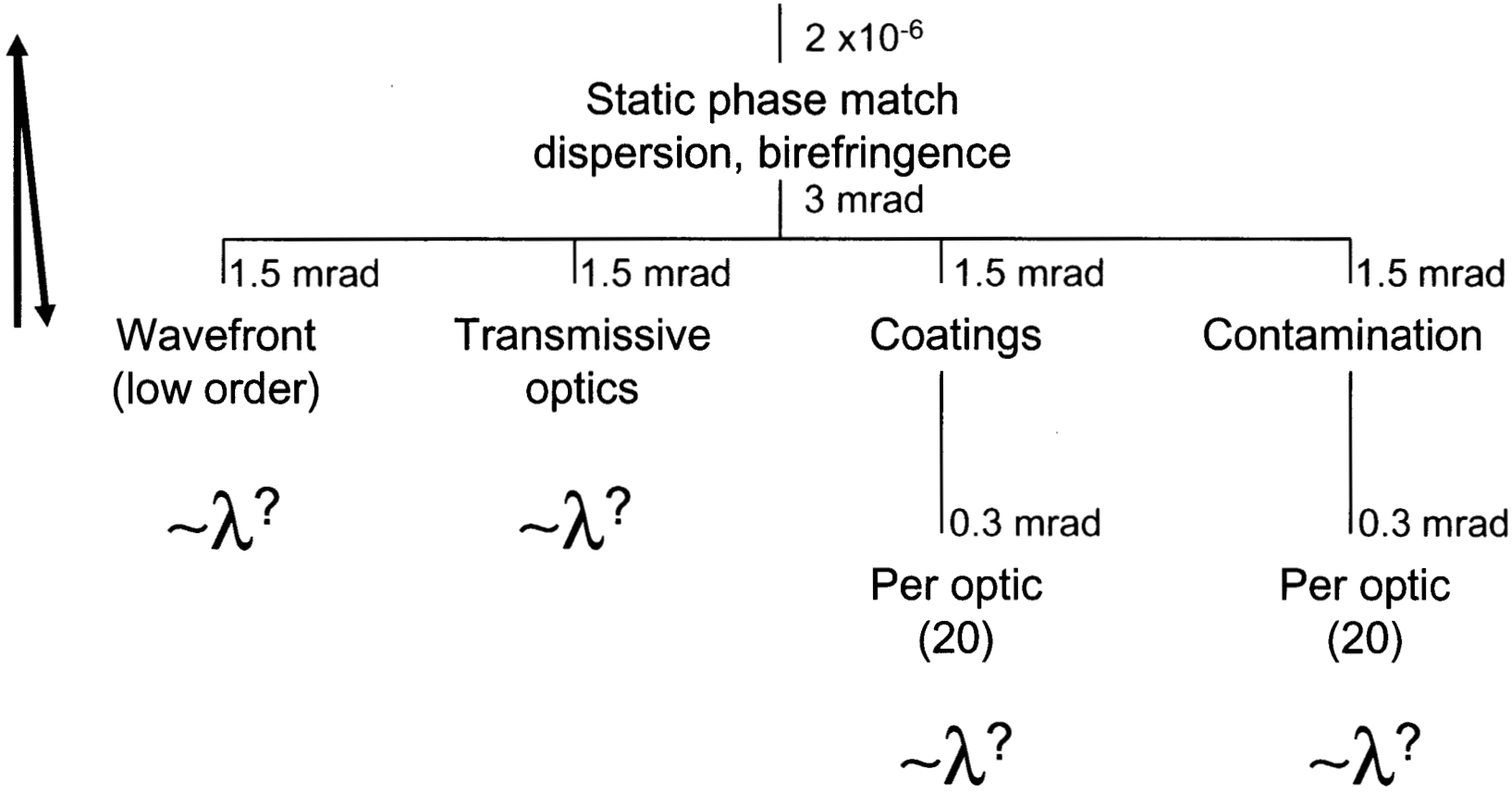


Intensity Match Requirements



* @ λ = 7 um

Phase Match Requirements



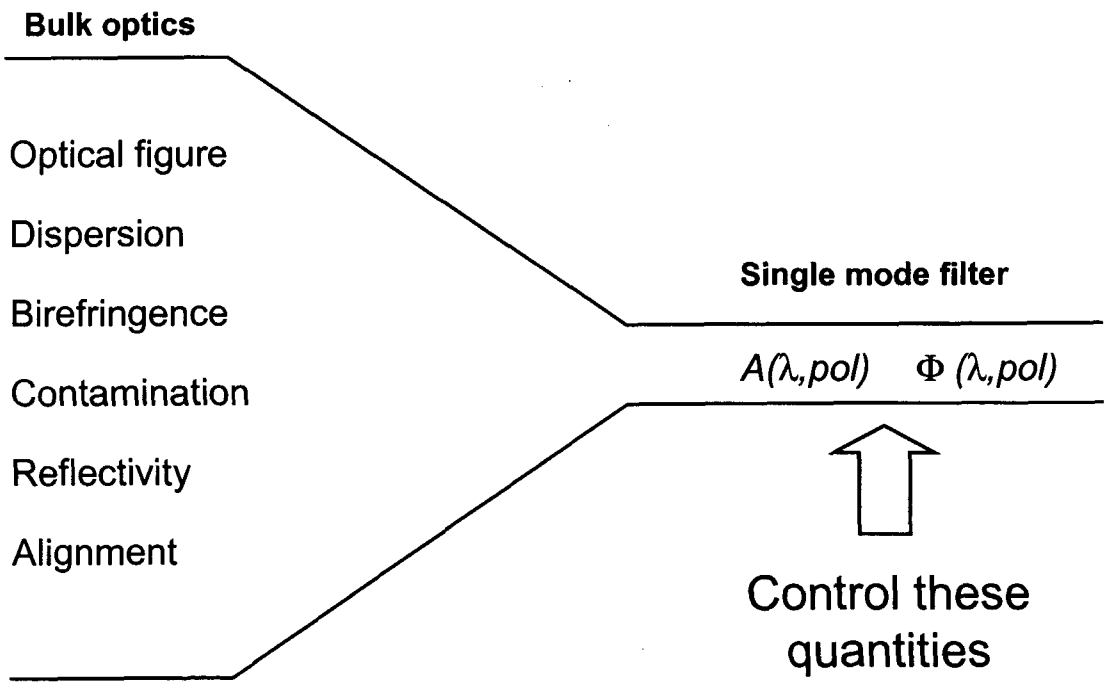
Many very tight requirements
Each with different spectral dependence

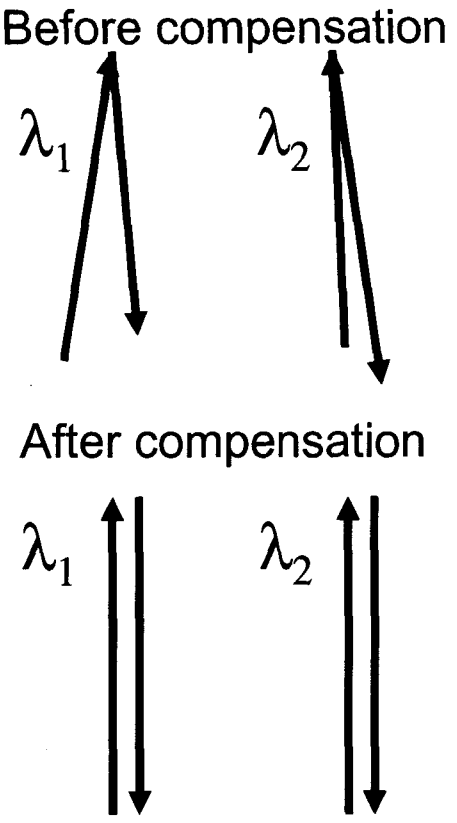
Challenges for current approach

- Nulling is a system-wide issue, driving tight tolerances…
  - primary mirror
  - beam transport
  - coatings
  - beam combiners
- …and challenging Integration & Test
- Difficult to achieve deep null over broad bandwidth (7-20 um) with single nuller
- Null is sensitive to in-flight perturbations, e.g.
  - Contamination on optical surfaces
  - Mis-alignment

New approach

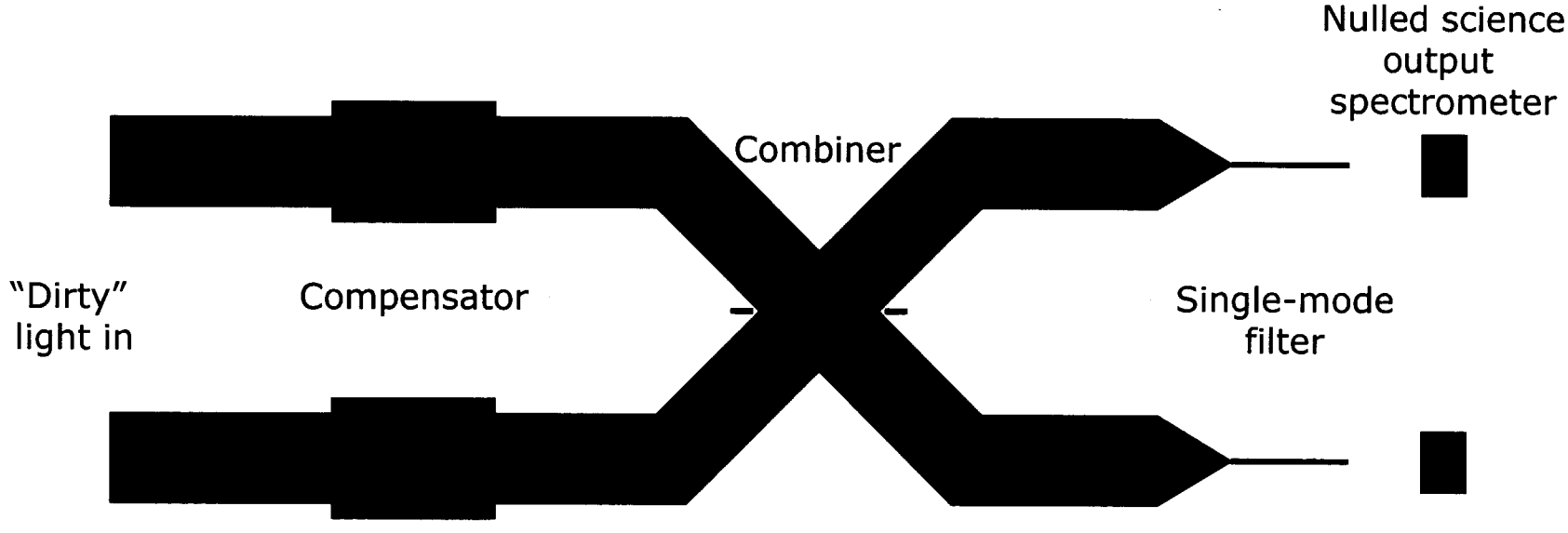
Include a compensator to actively control amplitude and phase for each polarization and wavelength at low bandwidth (< f_{chop})



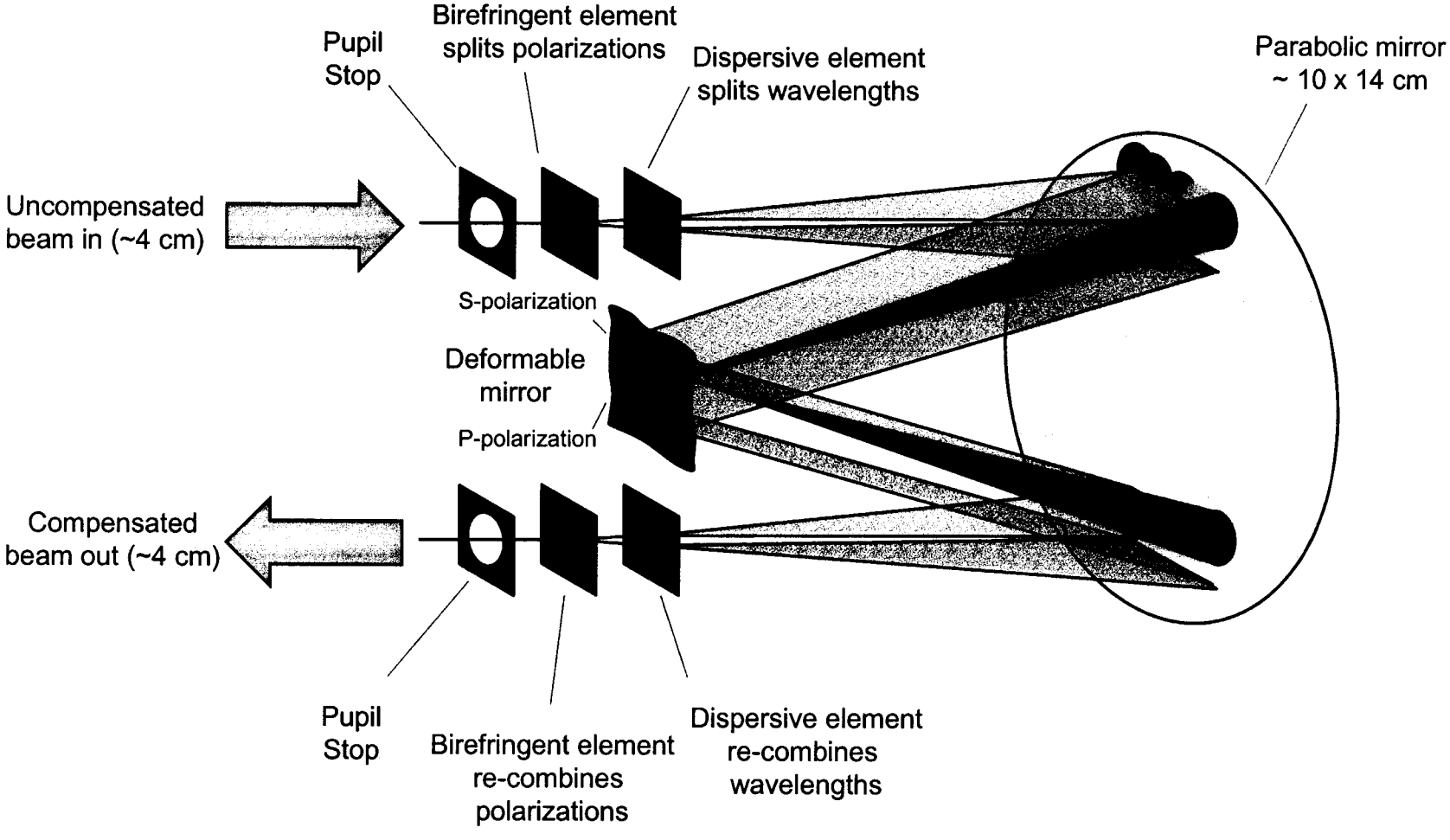


Compensator requirements

- Control (A,ϕ) independently at each {λ, pol}
- Path lengths matched between units at each {λ, pol}
- Minimal impact on throughput

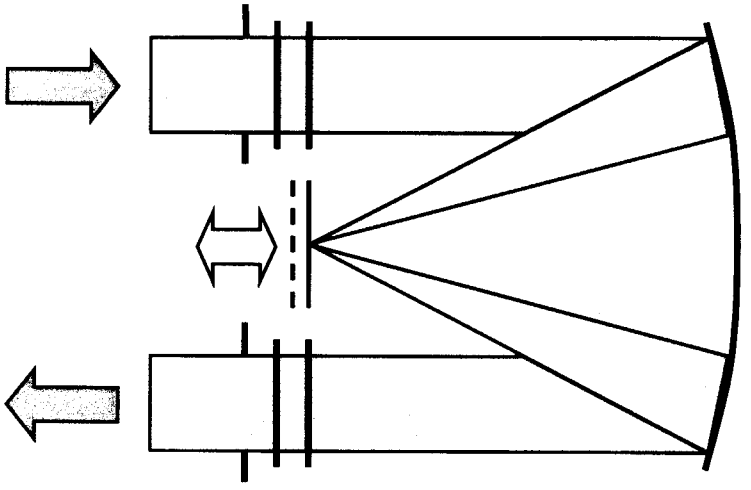


Possible Compensator Design

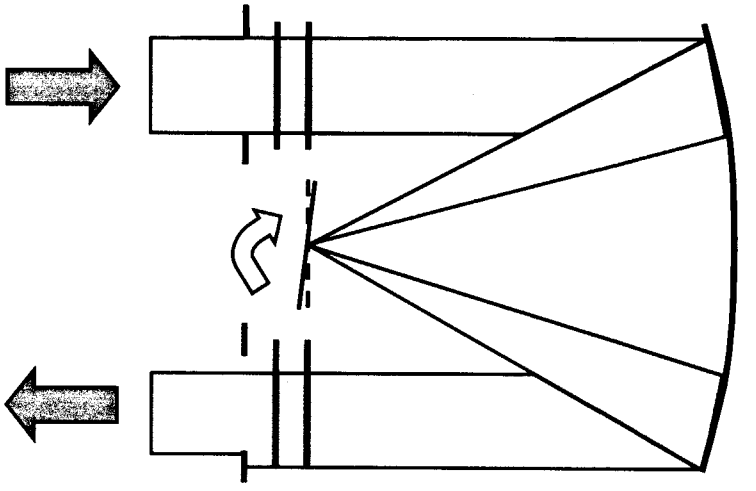


Phase and Amplitude Control

Phase control with piston*:



Amplitude control with tilt*:



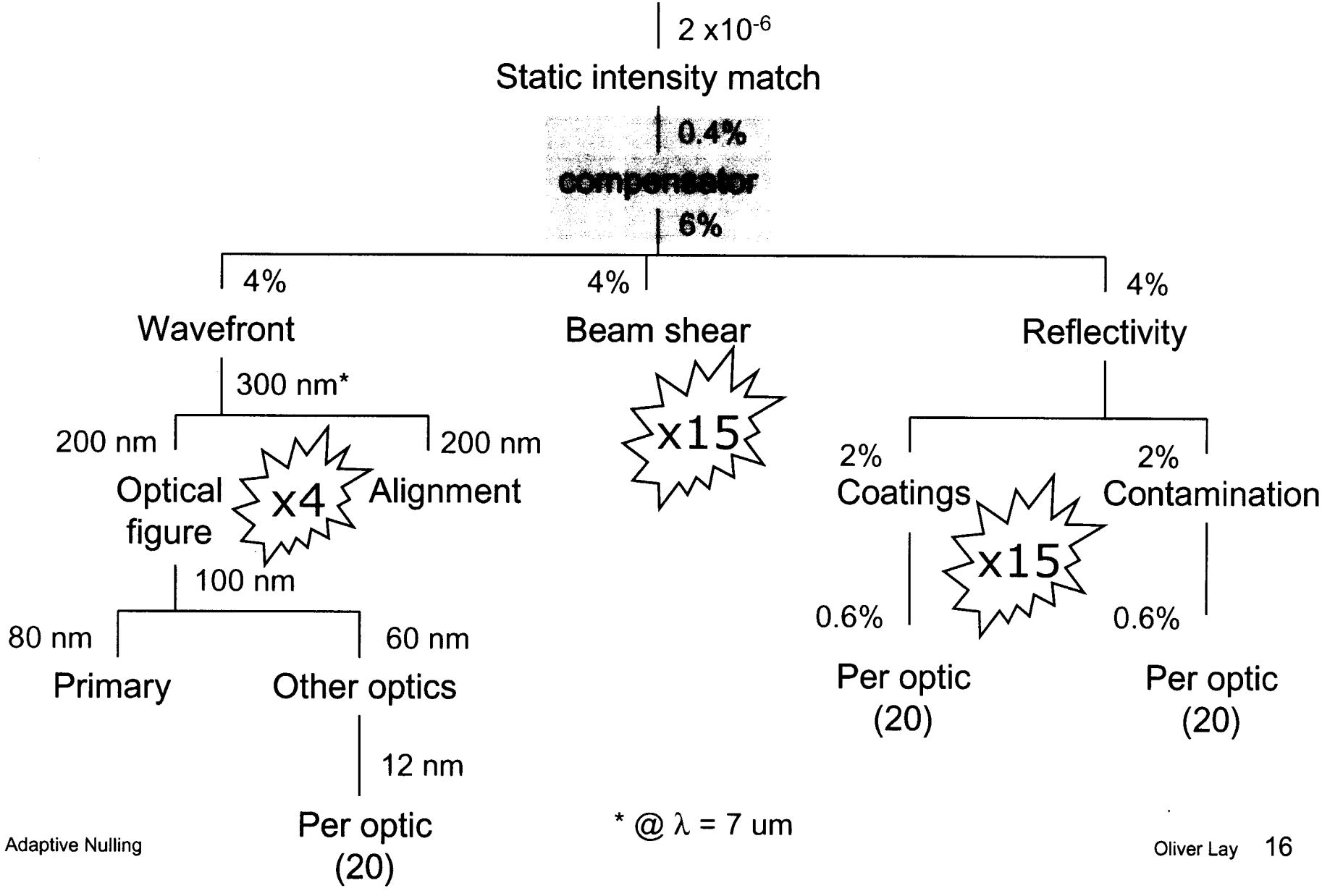
- Deformable mirror allows independent control of piston and tilt at each wavelength and polarization
- Nulled science output used as the sensor with simple iterative feedback loop
  - Local Zodi ~100 photons / s in each of ~20 chans => low bandwidth (tens of seconds)

* Side view, shown for single wavelength & polarization

Advantages of adaptive nulling

- Relax manufacturing and alignment tolerances (nuller, main optics, beam-train)
- Robust to in-flight perturbations (e.g. contamination, misalignment)
- Potential increase in bandwidth (turns broadband nuller into monochromatic single pol)
- Allows greater flexibility and simplicity in optical design (freedom from symmetry)
- Converts a system problem into a component problem, easing I&T

Intensity Match Requirements



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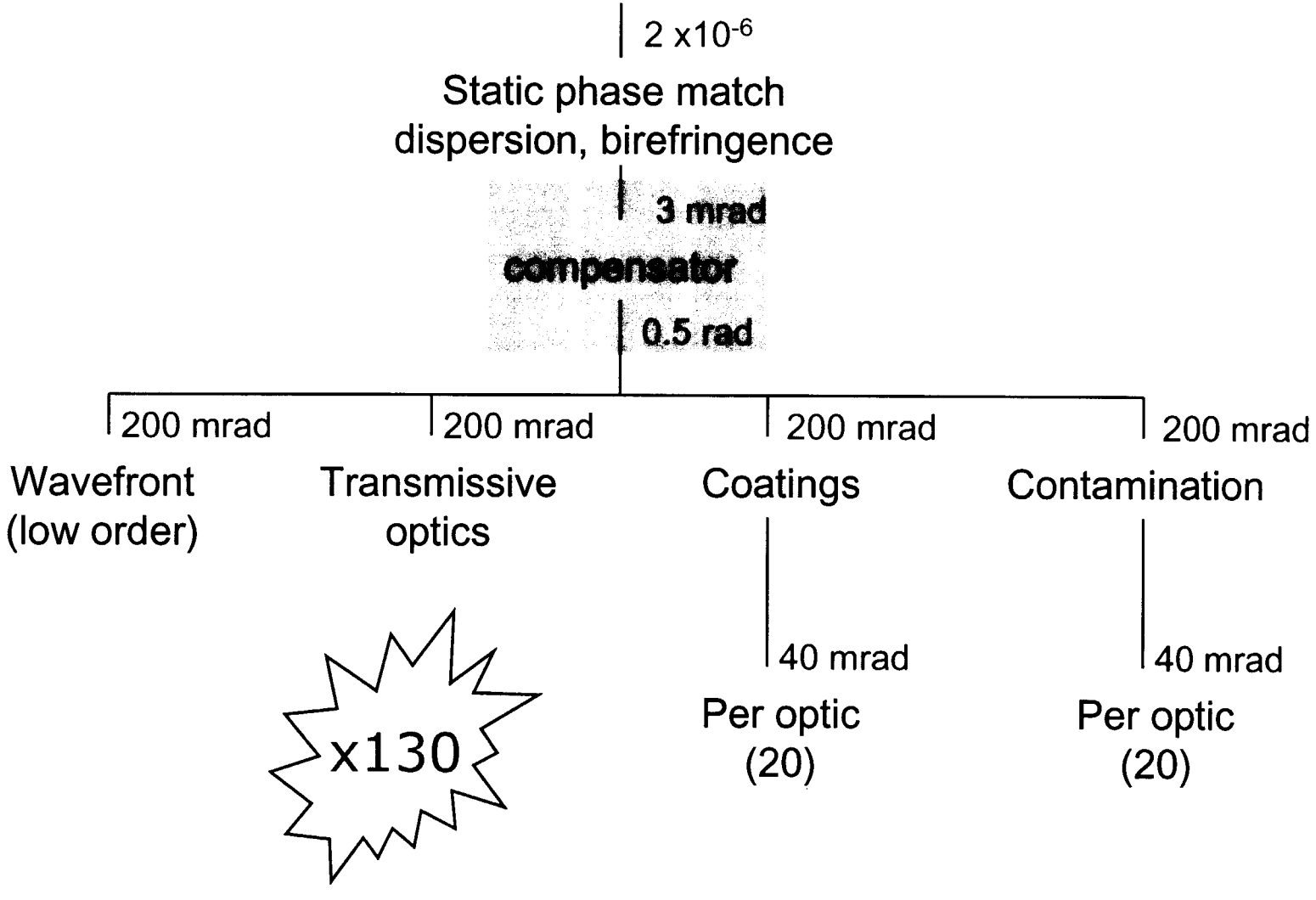
Phase Match Requirements



Challenges for adaptive nulling

- Retain high throughput
  - Alignment
  - Good focus over broad passband
- Accommodate metrology
- Components for mid-IR
  - Birefringent material

Key compensator parameters

- Precision
- Stability
- Dynamic range
- Optical bandwidth

Adaptive Nulling with Integrated Optics

- As IO technology develops and matures, it may become possible to implement an Adaptive Nulling compensator using Integrated Optics technology
- Combine compensator, nuller, spatial filter and detectors
- Compact and rugged
- Probably beyond current state-of-the-art

Summary

- A successful demonstration of Adaptive Nulling would lead to TPF/DARWIN interferometer designs that are
  - Cheaper (relaxed tolerances, less analysis needed)
  - More robust
  - More flexible
  - Easier to integrate and test

- An Adaptive Nulling compensator looks feasible with current technology